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Prediction and Adaptation of Military Natural Infrastructure in Response to Climate Change: Forest Modeling

Fiscal Year 2011 Progress Update

Patrick J. Guertin, Scott A. Tweddale, and George Z. Gertner

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Final report

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Under Work Unit No. 62272, “Base Facilities Environmental Quality”

Abstract

Federal legislation and Department of Defense (DoD) policy initiatives have created compliance requirements for the sustainability of military lands that include addressing climate-change impacts. Climate change will be an accelerant of current stressors in the natural environment and will increase military installations' burden for regulatory compliance in areas such as clean air, clean water, and protected species' habitats. Thus, future climate variation has a direct link to the sustainability of land resources and the impact of change to those resources on the military training mission. Many military lands, especially in the southeastern portion of the United States, feature forests as the predominant land cover. The overall objective of this work unit, "Prediction and Adaptation of Military Natural Infrastructure in Response to Climate Change: Forest Modeling," is to evaluate Army forest management planning as impacted by future climate variability scenarios. This report outlines progress for fiscal year (FY) 2011 on work unit Tasks 1–3 which are model selection, data development and acquisition, and model modification and parameterization.

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Preface

This study was conducted for the Office of the Assistant Secretary of the Army for Acquisition, Logistics, and Technology (ASA[ALT]) under Research, Development, Test, and Evaluation Program A896, “Base Facilities Environmental Quality,” Project 622720, “Prediction and Adaptation of Military Natural Infrastructure in Response to Climate Change: Forest Modeling.” The technical monitor was Kathleen McLaughlin, DAIM-ED-N.

The work was performed by the Ecological Processes Branch (CN-N) of the Installations Division (CN), U.S. Army Engineer Research and Development Center – Construction Engineering Research Laboratory (ERDC-CERL). At the time of publication, Bill Meyer was Chief, CEERD-CN-N; Michelle Hanson was Chief, CEERD-CN; and Alan Anderson was the Technical Director for Military Ranges and Lands. The Deputy Director of ERDC-CERL was Dr. Kirankumar Topudurti and the Director was Dr. Ilker Adiguzel.

COL Kevin J. Wilson was the Commander and Executive Director of ERDC, and Dr. Jeffery P. Holland was the Director.

Unit Conversion Factors

Multiply	By	To Obtain
acres	4,046.873	square meters
inches	0.0254	meters

Abbreviations

Term	Spellout
3-PG	physiological principles predicting growth (model)
dbh	diameter at breast height
CEQ	Council on Environmental Quality
DoD	Department of Defense
ERDC-CERL	Engineer Research and Development Center – Construction Engineering Research Laboratory
ESA	Endangered Species Act
FIA	Forest Inventory and Analysis
FVS-sn	Forest Vegetation Simulator – southern variant (model)
FY	fiscal year
IPCC	Intergovernmental Panel on Climate Change
LiDAR	Light Detection and Ranging
NEPA	National Environmental Policy Act
TES	threatened and endangered species
USFS	US Forest Service
VTU	Virginia Technological University

1 Introduction

1.1 Background

This report covers progress for fiscal year (FY) 2011 on the 6.2 direct-funded work unit “Prediction and Adaptation of Military Natural Infrastructure in Response to Climate Change: Forest Modeling.”

Several national and Department of Defense (DoD) policy initiatives are driving requirements for vulnerability assessments, planning, and adaptation strategies to address climate-change impacts on military lands. For example, the 2010 Quadrennial Defense Review highlighted the challenges of climate change on the DoD mission and installation infrastructure, including the natural environment (DoD 2010a). Also, the first DoD Strategic Sustainability Performance Plan, covering FY 2010-2020, called for a comprehensive assessment of all military installations to assess the potential impacts of climate change on each installation’s mission and natural resources (DoD 2010b).

Compliance requirements will increase since climate change will modify all aspects of the natural environment including water resources, air quality, soils, and vegetation. Climate change will be an accelerant of current stressors in the natural environment that will increase installations’ burden for regulatory compliance. For example, all military installations are subject to regulatory requirements of the Clean Air Act[1] and Clean Water Act.[2] In addition, approximately 99 Army installations have compliance requirements under the Endangered Species Act (ESA), and many of the Army’s major power projection installations in the southeastern United States have multiple species occurrences. Consideration of climate change impacts in ESA listing actions and Section 7 consultations are increasing. The President’s Council on Environmental Quality’s progress report (CEQ 2010) provides guidance to all federal agencies to evaluate environmental consequences of climate change in National Environmental Policy Act of 1969 (NEPA)[3] evaluations of federal actions.

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[1] Clean Air Act, Public Law 91-604, 31 December 1970, 42 U.S.C. 7401 et. seq.; as amended in 1990 (PL 101-549).

[2] Clean Water Act, Public Law 95-217, 33 U.S.C. 1251 et, seq, 1972 as amended in 1997, 2002.

[3] NEPA, Public Law 91-190, January 1970.

In addition to its direct impacts on compliance issues, including threatened or endangered species (TES) and TES habitat, future climate variation has a direct link to the sustainability of land resources that impact the military training mission. Temperature, precipitation, and similar parameters linked to climate change are essential in determining vegetation suitability and robustness. In respect to the southeastern United States, methods are needed to evaluate the impacts of climate change on forest land resources because it is the predominant cover type on a majority of military lands. Forest parameters such as structure, species composition, and species growth/health are determining factors in meeting military training, conservation, and commercial management objectives.

1.2 Objective

The overall objective of this work unit is to evaluate general robustness and resilience of Army forest management planning as impacted by future climate variability scenarios. This will be achieved through a series of sub-objectives including:

1. Modify or develop a means to forecast future forest parameters incorporating climate variability.
2. Develop a remote sensing protocol for populating algorithms associated with sub-objective 1.
3. Evaluate general robustness and resilience of land-management planning scenarios considering effects of climate change scenarios.

1.3 Approach

This work unit will develop or modify and apply empirical or mechanistic forest dynamics models to assess the robustness and resilience of military land-management planning in support of military training and conservation sustainability goals under the uncertainty of future climate change scenarios. Emphasis will be placed on efficiently and systematically reducing sources of uncertainties that are controllable and cost effective.

Climate evaluations for this work will be based on Intergovernmental Panel on Climate Change (IPCC)-developed climate change scenarios. This study's geographic focus will be the Sandhills Fall Line ecoregion of the southeastern United States, with Fort Bragg, North Carolina, as the study location. Within this ecoregion, upland loblolly and longleaf pine ecosystems will be the assessment focus based on their significant contribution

to land area as related to military training lands/ranges and their importance to TES. Models used in this effort will be currently accepted models which will be modified to incorporate effects of climate change—most notably being growth and mortality functions.

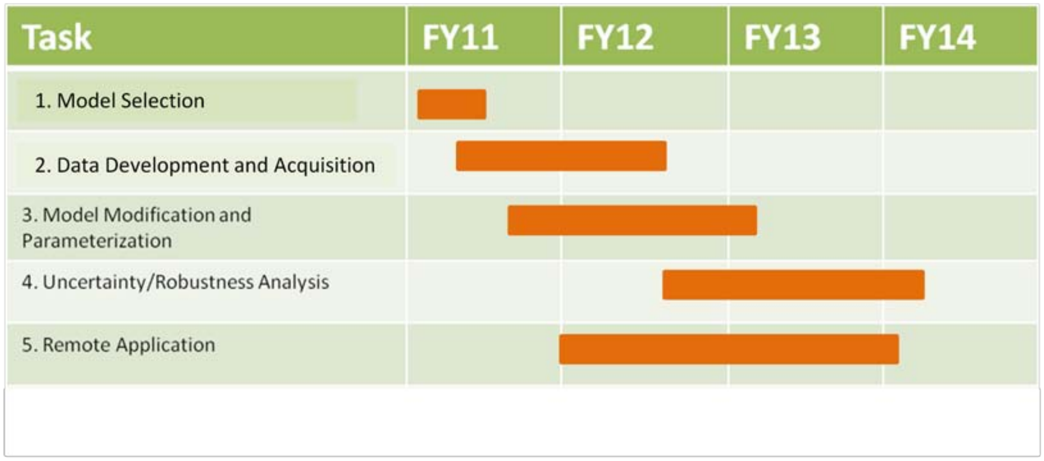

Figure 1. Work package task schedule.

During the full life cycle of this work package (FY11–14, Figure 1), the following five major task areas will be completed. To meet FY 2011 project execution goals, progress in Tasks 2 and 3 and completion of Task 1 are required (see Section 2 for details of progress).

1. Identification of a mechanistic or ecological model that can be modified for climate change analysis—the physiological principles predicting growth (3-PG) model, which is widely accepted in ecological circles, and the U.S. Forest Service's FVS-sn model were primary contenders.
2. Development and acquisition of ecological and climate scenario data for model calibration and evaluation.
3. Model modification and parameterization of the selected model.
4. Comprehensive uncertainty/sensitivity analysis of the model and evaluation of current Army forest management scenarios in meeting training, conservation, and commercial goals.
5. Incorporation of remotely sensed data for model parameterization and large-scale landscape applications.

2 Fiscal Year 2011 Task Progress

As stated in Chapter 1, completion of Task 1 and progress on Task 2 and Task 3 is required during FY 2011.

2.1 Task 1 status (model selection)

Two scientifically accepted models were identified and modified to operate under climate change conditions in the southeastern U.S.: the 3-PG (physiological principles predicting growth) process model developed by Landsberg and Waring (1997) and the FVS-sn model developed by the U.S. Forest Service(Forest Vegetation Simulator - Southern variant).[1] The 3PG model relies on ecological and mechanistic principles to derive predictions; while FVS-sn is a traditional forest growth model that utilizes detailed forest structure parameters and sub-models for increment growth, mortality, recruitment, etc. The models offer different advantages and both are widely accepted by the ecological and land management communities.

Both models were evaluated in terms of ease of modification and applicability as a projection system to examine future Army land management challenges. The 3PG model utilizes climate and other environmental input, making it readily available for application; however, the model's simplistic design and inflexibility make it unsuitable for in-depth evaluation of future forest conditions related to Army activities and requirements. The reason for this limitation is because the 3PG model simulates only even-aged monocultures, a land management scenario that does not meet Army needs. The Army’s needs include modeling for potential multiple species and age-classes; even-aged monocultures frequently occur with frequencies on commercial lands, not Fort Bragg.

By contrast, the FVS-sn model has the ability to simulate a wide range of forest structures and species (e.g., uneven age classes, mixed species, management options). It also incorporates separate algorithms for major life-processes, including mortality and increment growth, both of which are concerns in environments with climate uncertainties (Xu et. al. 2009). Additionally, FVS-sn can incorporate modules that simulate fire and car-

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[1] http://www.fs.fed.us/fmsc/fvs/

bon cycle effects, adding flexibility to future analysis. FVS-sn does not currently incorporate climate variables; however, modification is possible to incorporate this (Crookston et. al. 2005 2010).

FVS-sn was selected as the modeling system for the work unit, given its demonstrated ability to be modified to incorporate climate change and variation, and its flexibility to examine the Army's current and future land requirements.

2.2 Task 2 status (data development and acquisition)

Task 2 involved developing the ecological and climate scenario datasets required to execute Task 3 (model calibration), Task 4 (model evaluation for robustness and uncertainty), and Task 5 (landscape application of model in remote application).

2.2.1 Model calibration, variables

The FVS-sn model projects forest development through a suite of submodels that predict structural change in the forest on an individual tree basis. The two primary submodels that need to be considered for calibration are those for diameter growth and for mortality. Data needed to recalibrate for climate requires the standard variables used to calibrate the non-climate submodels, along with those environmental variables most likely to impact growth and mortality due to climate. Standard FVS parameters include diameter at breast height (dbh), site index, height to live crown, total height, basal area, trees per acre. (Dixon 2012). Environmental variables linked to influencing tree and forest development are listed below (Rehfeldt et. al. 2006).

- Mean annual temperature
- Mean temperature in the coldest month
- Minimum temperature in the coldest month
- Mean temperature in the warmest month
- Maximum temperature in the warmest month
- Mean annual precipitation
- Growing season precipitation, April-September
- Summer-winter temperature differential
- Degree-days >5°C
- Degree-days <0°C
- Minimum degree-days <0°C

- Julian date of the last freezing date of spring
- Julian date of the first freezing date of autumn
- Length of the frost-free period
- Degree-days >5°C accumulating within the frost-free period
- Julian date the sum of degree-days >5°C reaches 100
- Annual moisture index
- Summer moisture index
- Ratio of summer precipitation to total precipitation

The data source used for model calibration was the forest inventory data from the USDA Forest Service's Forest Inventory and Analysis (FIA) program. FIA data represents the best available long-term (50^+ yr) information for the southeastern United States. Data for soils and related parameters will come from Soil Survey Geographic (SSURGO) data from the USDA Natural Resource Conservation Service. Climate data from USDA Forest Service Forestry Sciences Laboratory, Moscow, Idaho is applicable to a wide range of climate scenarios.

2.2.2 Evaluation of model modification

The climate-sensitive version of FVS-sn developed in this effort will be used to evaluate general robustness and resilience of land management planning scenarios that consider the effects of climate change. In order to accomplish this, the modified version of FVS must be evaluated to develop an understanding of performance characteristics of projections.

The initial step is to evaluate uncertainties in forest predictions (i.e., compare projected forest values with what would be expected). Additionally, forest model(s) parameter sensitivity needs to be accounted for. These evaluations will allow for an understanding of model capabilities and where potential improvements can be made. Methods needed for reducing sources of uncertainties and errors that are controllable and cost effective are included in the scientific literature (Xu and Gertner 2008; Xu, Gertner, and Scheller 2009; Xu and Gertner 2009).

Data requirements for evaluation are similar to those for calibration. Modification of the model is expected to follow a format similar to that used by Crookston et. al. (2005), where projections from the base model's diameter and mortality functions are modified through climate submodels. With this scenario, data requirements would be the same standard FVS parameters from calibration, along with a subset of the climate variables identified

in Task 3. Full data requirements will be dependent on completion of the climate modifications to FVS. However, data will be in hand from previous acquisition.

2.2.3 Evaluation of landscape application methodology

Application of the climate sensitive FVS-sn model developed in this effort required a methodology for data population (e.g., stand parameter data source) for use in landscape decision-making processes across large-scale decision applications. Historically, data for these types of exercises has come from ground-based stand inventories of a site; however, that process is cost prohibitive for large-scale climate change studies. To accommodate this need, a methodology will be developed to populate landscape model application with remote-sensed data.

Data for the landscape application will be provided via a completed research project that analyzed the habitat of the red-cocked woodpecker via remote sensing (Tweddale et. al. 2008). This dataset contains many of the common structural forest parameters needed to populate the forest growth model. Field data collected included stem location, dbh, height, height to live crown, crown dimensions and species for all overstory stems, and stem location and crown dimensions for understory stems. This field data was compiled for 61 circular field plots (~ 0.1 acre) distributed across portions of Fort Bragg, McCain State Forest Tract, and adjacent private landin North Carolina. Discrete return LiDAR data, collected for the same study areas during the project (ibid.), was also compiled. Output from a LiDAR-based stem identification algorithm was analyzed and summarized into correctly identified (matched), omission, and commission stems by considering only those stems with a field-measured dbh >4 in. (Table 1).

Table 1. Confusion matrix of LiDAR-based stem identification compared to field data.

FIELD DATA				LiDAR DATA	
	Hardwood	Loblolly	Longleaf		
Matched	10	49	101	Matched	160
Omission	34	1	36	Commission	84
Total	44	50	137	Total	244
Percent Matched	23	98	74	Percent Matched	66
Percent Omission	77	2	26	Percent Commission	34

The confusion matrix in Table 1identified a problem associated with identification of hardwood stems when using LiDAR data. However, after eliminating hardwood stems (which will not be modeled in this research effort) and considering only Loblolly and Longleaf stems, 79% of the field-measured stems were correctly identified with LiDAR data, with an omission error of 21%.

To investigate this omission error rate, selected plots representing the range of stem-finding model performance were identified and visited in the field in 2011 to assess the utility of a LiDAR-based stem identification algorithm for creating and attributing accurate stand maps for this study. Field observations of the plots revealed that LiDAR errors of omission were primarily associated with mid-story hardwood stems. Field observations also revealed that many of the omission and commission errors were occurring on the edge of plots, and therefore could be attributed to errors in the location of the plot data with respect to the LiDAR data rather than errors in the LiDAR-based stem identification model (i.e., stems were considered on the plot when measured in the field, when in fact they were outside of the plot). Therefore, based on observations from the 2011 field visits to selected plots and assessment of the confusion matrix, it was determined that the LiDAR-based stem identification model is capable of producing a landscape-scale, attributed-stem map that is suitable for parameterization of the FVS model.

Errors were also noted in height to live crown and diameter estimates empirically derived from height estimates, and methods were identified to reduce errors in estimates of these parameters. Initial linear regression analysis of the relationship between field-measured stem height and field-measured dbh identified a moderately strong correlation (R 2 = 0.73). Field-measured stem height was also moderately correlated with field-measured height to live crown measurements (R 2 = 0.78). However, both prediction models included all field-measured stems on the plot and once stems <4in. dbh were removed from the regressions, the amount of variance in dbh and height to live crown that could be predicted by using stem height was too low for using this technique to parameterize the FVS model at a landscape scale. This problem was identified as a critical point of emphasis for analysis in FY 2012; in other words, utilization of LiDAR data to parameterize the model will result in highly accurate estimates of stem height, but dbh and height to live crown cannot be measured directly and therefore must be inferred from height measurements. Additional inde-

pendent variables that will be extracted from the LiDAR data in an attempt to improve estimates of dbh will include the use of relative stem density, crown size, and height to live crown.

2.3 Task 3 status (model modification and parameterization)

Based on the decision in Task 1 work (selection of the USFS FVS-sn model), a plan was formulated to incorporate climate parameters into FVS that will modify projections accordingly. Following discussions with the Director of the USFS Forest Management Service Center, a professor from the Department of Forestry at Virginia Technological University (VTU) was selected to be the lead researcher for model calibration. This decision was heavily weighted on VTU's experience with climate change and the FVS-sn model, and a need to secure additional technical resources to expand ERDC-CERL's capabilities to efficiently execute the work package. A finalized technical plan for executing the climate modification of the model will be completed in the first quarter of FY 2012, with a completed product by first quarter of FY 2013.

3 Summary of Progress for FY 2011

Below is a synopsis of progress made on each of the three tasks that were scheduled for attention in FY 2011.

3.1 Task 1

The Task 1 goal of model selection was completed following the analysis of two models and the selection of FVS-sn as the study model. Once modified to accept climate variability, FVS-sn is suitable for the project goal of evaluating impacts of climate change on Army lands in the southeastern United States. The modification process has been documented, and a mechanism is in place to implement the modifications on the FVS-sn model.

3.2 Task 2

Task 2 goals for FY 2011 were met through identifying necessary data requirements to complete project goals and actions were initiated to develop or obtain datasets. Sources for these datasets include: (1) previous ERDC-CERL research, with modification to improve prediction; (2) obtaining FIA through cooperation with the USFS; and (3) data gathered in cooperation with staff at Fort Bragg and the North Carolina Department of Agriculture.

3.3 Task 3

Task 3 goals for FY 2011 were met with the implementation of a cooperative agreement to work with the VTU Department of Forestry to modify the FVS-sn model as needed for study use.

3.4 Next steps

Overall, progress is on schedule with the initial research plan. There are no foreseeable obstacles for future progress as of the end of FY 2011. Agreements are in place with VTU to collaborate on FVS-sn modification to account for climate change parameters. Data requirements are scoped and initial data acquisition is progressing. FY 2012 will focus on finalizing data, development of climate modifications to FVS-sn, initial evaluation of model input, and developing input data for FVS-sn from remote sensing platforms.

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14. ABSTRACT

Federal legislation and Department of Defense (DoD) policy initiatives have created compliance requirements for the sustainability of military lands that include addressing climate-change impacts. Climate change will be an accelerant of current stressors in the natural environment and will increase military installations' burden for regulatory compliance in areas such as clean air, clean water, and protected species' habitats. Thus, future climate variation has a direct link to the sustainability of land resources and the impact of change to those resources on the military training mission. Many military lands, especially in the southeastern portion of the United States, feature forests as the predominant land cover. The overall objective of this work unit, "Prediction and Adaptation of Military Natural Infrastructure in Response to Climate Change: Forest Modeling," is to evaluate Army forest management planning as impacted by future climate variability scenarios. This report outlines progress for fiscal year (FY) 2011 on work unit Tasks 1–3 which are model selection, data development and acquisition, and model modification and parameterization.

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